DRAGONFLY

A relocatable lander to explore Titan's prebiotic chemistry and habitability

Dragonfly TPS Sizing and Analysis

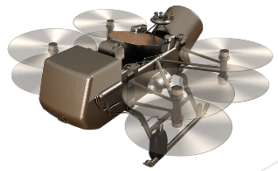
AIAA SciTech: Dragonfly Entry and Descent at Titan

Eric Stern and Milad Mahzari

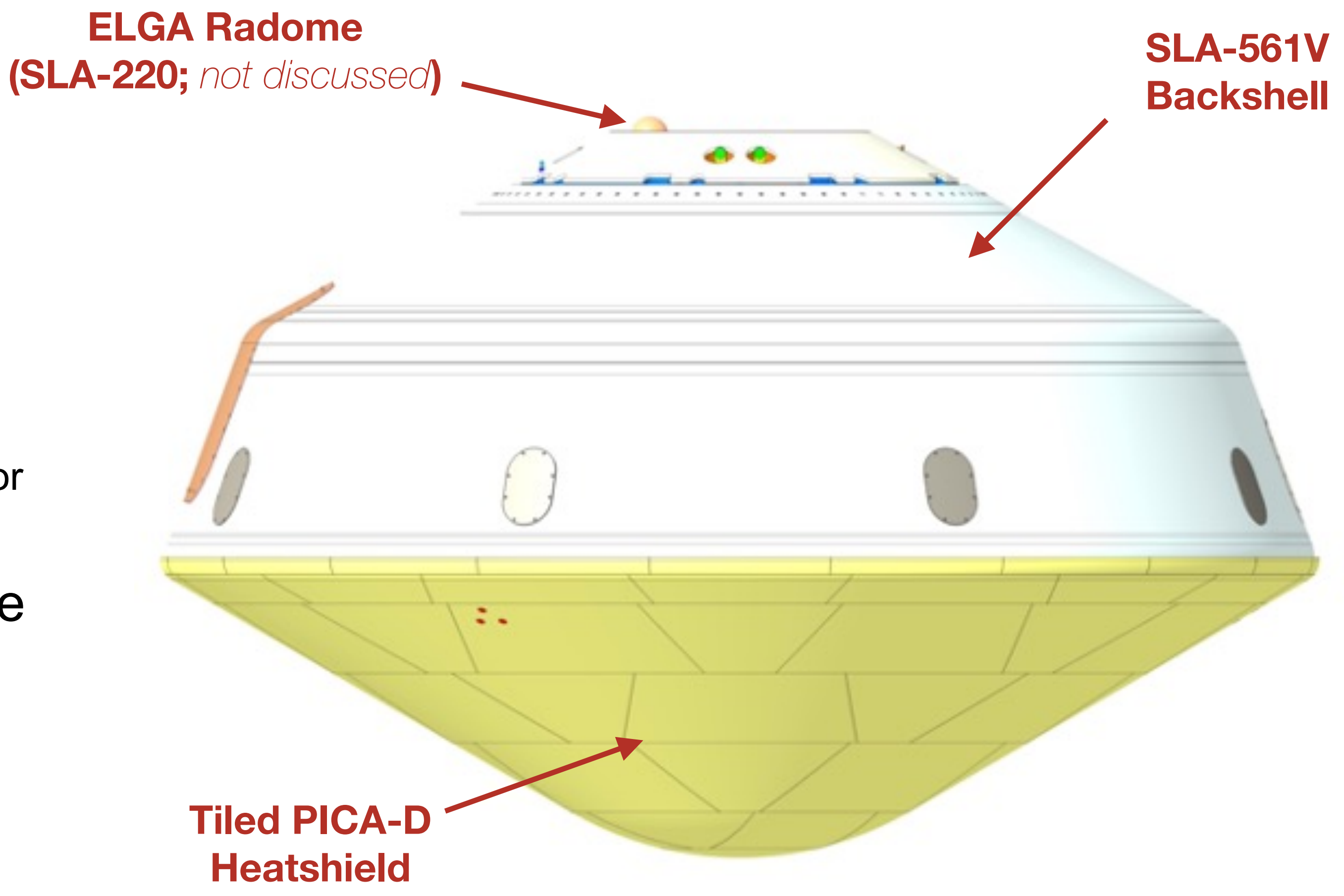
Outline

- **TPS Overview and Sizing**
  - System Overview
  - Sizing Methodology
- **Dragonfly-specific TPS Design Considerations**
  - Convective Cooling
  - Shoulder “Tooth” Conceptual Design
- **Summary**

Dragonfly TPS Sizing

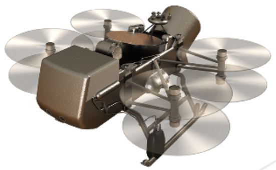


- Two primary TPS materials: PICA-D and SLA-561V
  - High TRL and used well within tested limits
  - Arc jet testing confirms performance
  - PICA-D has been qualified as drop-in replacement for heritage PICA
- TPS sizing & margin analysis uses mature processes developed during MSL/Orion
  - Design thicknesses carry unallocated margin



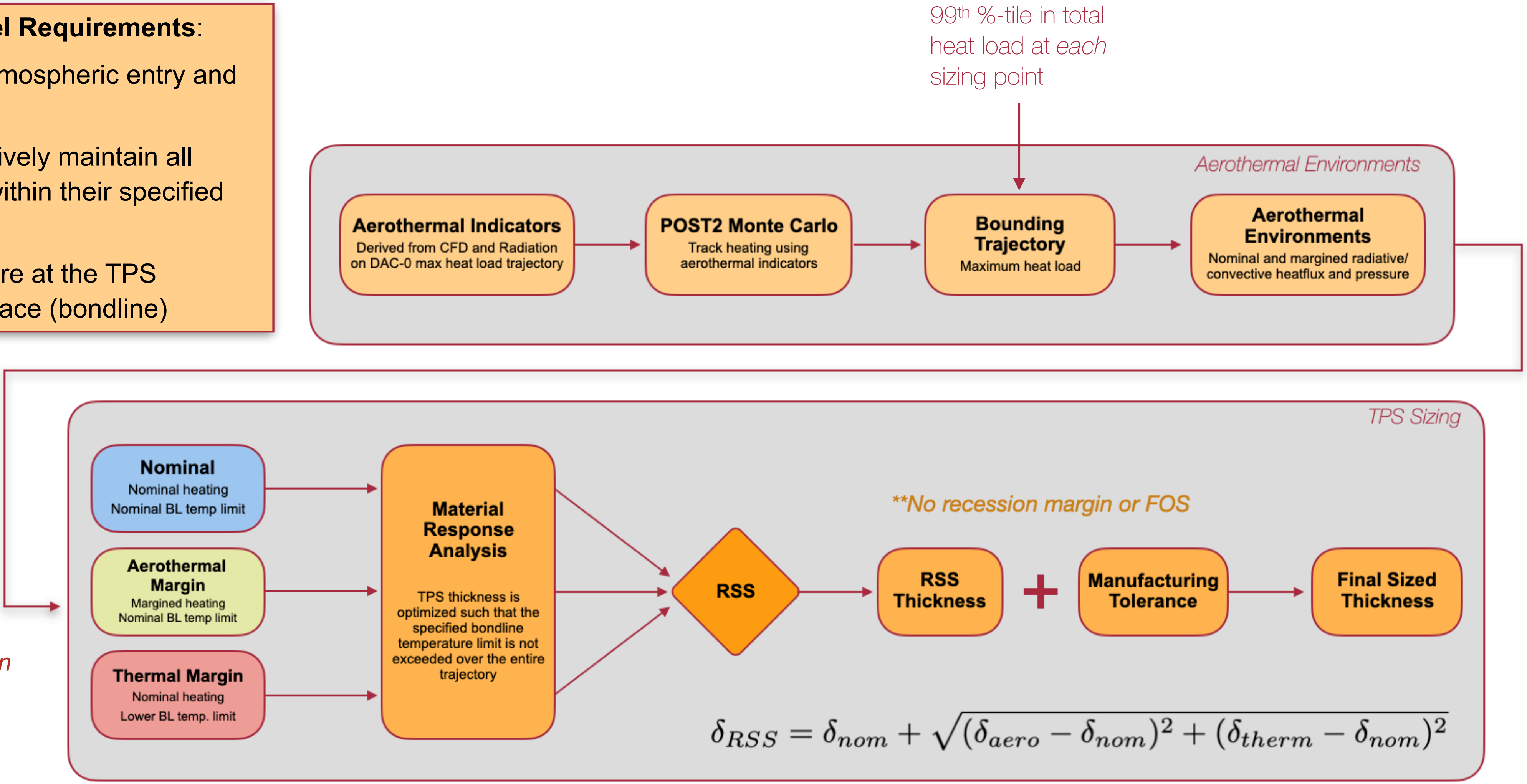
Schematic of the Dragonfly aeroshell with sized TPS material thicknesses

TPS Sizing Methodology



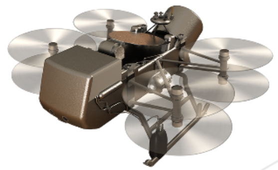
Driving Aeroshell System Level Requirements:

- The aeroshell shall survive atmospheric entry and descent
- The aeroshell TPS shall passively maintain all component temperatures to within their specified limits
  - ➡ i.e. specified temperature at the TPS material-structure interface (bondline)



✳ *Root sum square (RSS) margin approach same as used for MSL/Mars2020/etc.*

Sizing Points



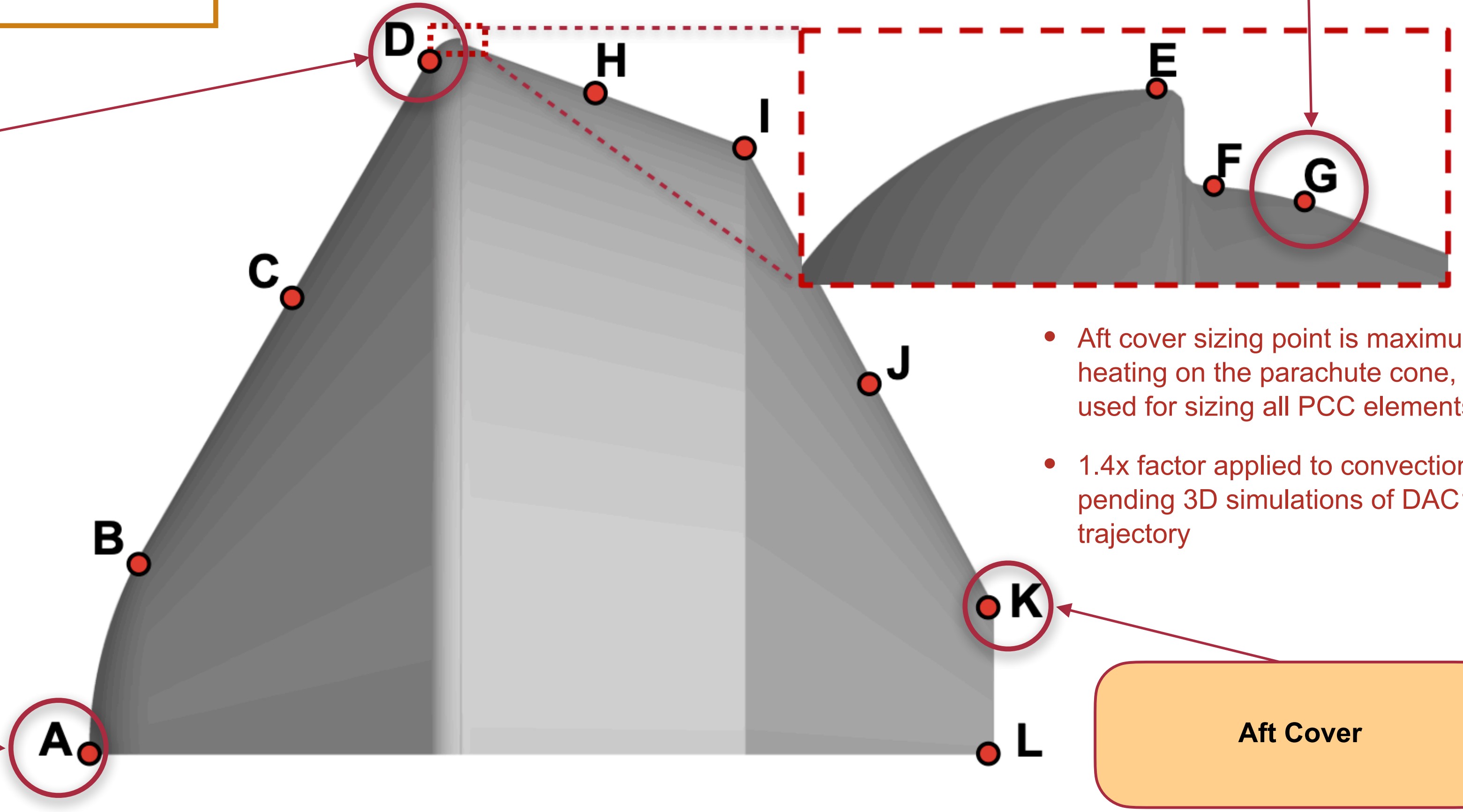
- Four points selected for sizing analysis
- Structural stack-up at each sizing point provided by LM structural analysis

- Aftbody shoulder is maximum aftbody environment

Aftbody Shoulder

Forebody Shoulder

- Forebody shoulder represents maximum heat flux, and heat load, but also thickest structural stack-up

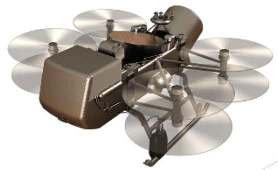


- Aft cover sizing point is maximum heating on the parachute cone, used for sizing all PCC elements
- 1.4x factor applied to convection, pending 3D simulations of DAC1b trajectory

Stagnation Point

Aft Cover

TPS Analysis Tool: FIAT



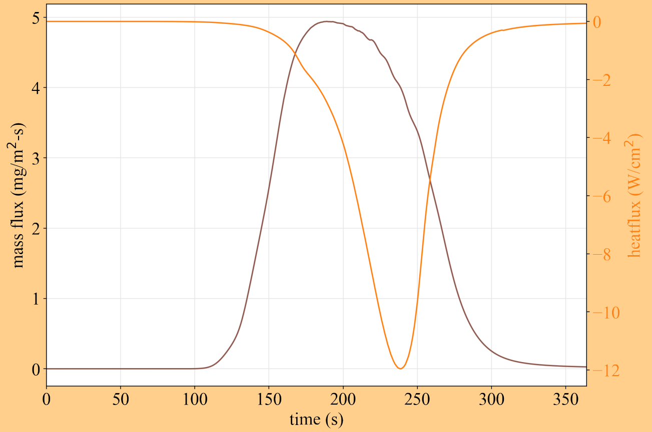
- Fully Implicit Ablation and Thermal response program (FIAT) version 3.2.0 used for all sizing calculations
- Standard within NASA (and largely in industry) for TPS response analysis and sizing
  - Used for several successful missions using Dragonfly TPS materials, such as MSL, Mars2020, Stardust, and many others
- One dimensional implementation of the governing equations for material response
  - Accurate for regions with low curvature and small gradients in the environment
  - Curvature can be simulated using cell volume construction according to SPHERICAL (nose tile) and CYLINDRICAL (shoulder tile) ratios
  - Multi-dimensional analysis, when required, performed using Icarus

Physical Boundary Condition:

- ***No thermochemical ablation*** expected for Dragonfly entry, due to lack of oxygen at Titan
- Direct heatflux boundary condition (FIAT option 3) used for sizing calculations

$$q_{conv} + \alpha q_{rad} - \sigma \epsilon_w \left(T_w^4 - T_\infty^4\right) - q_{cond} = 0$$

- Use of ablating BC (option 1) results in negative heatflux contribution of GSI terms
- Current approach is conservative, given equilibrium assumption



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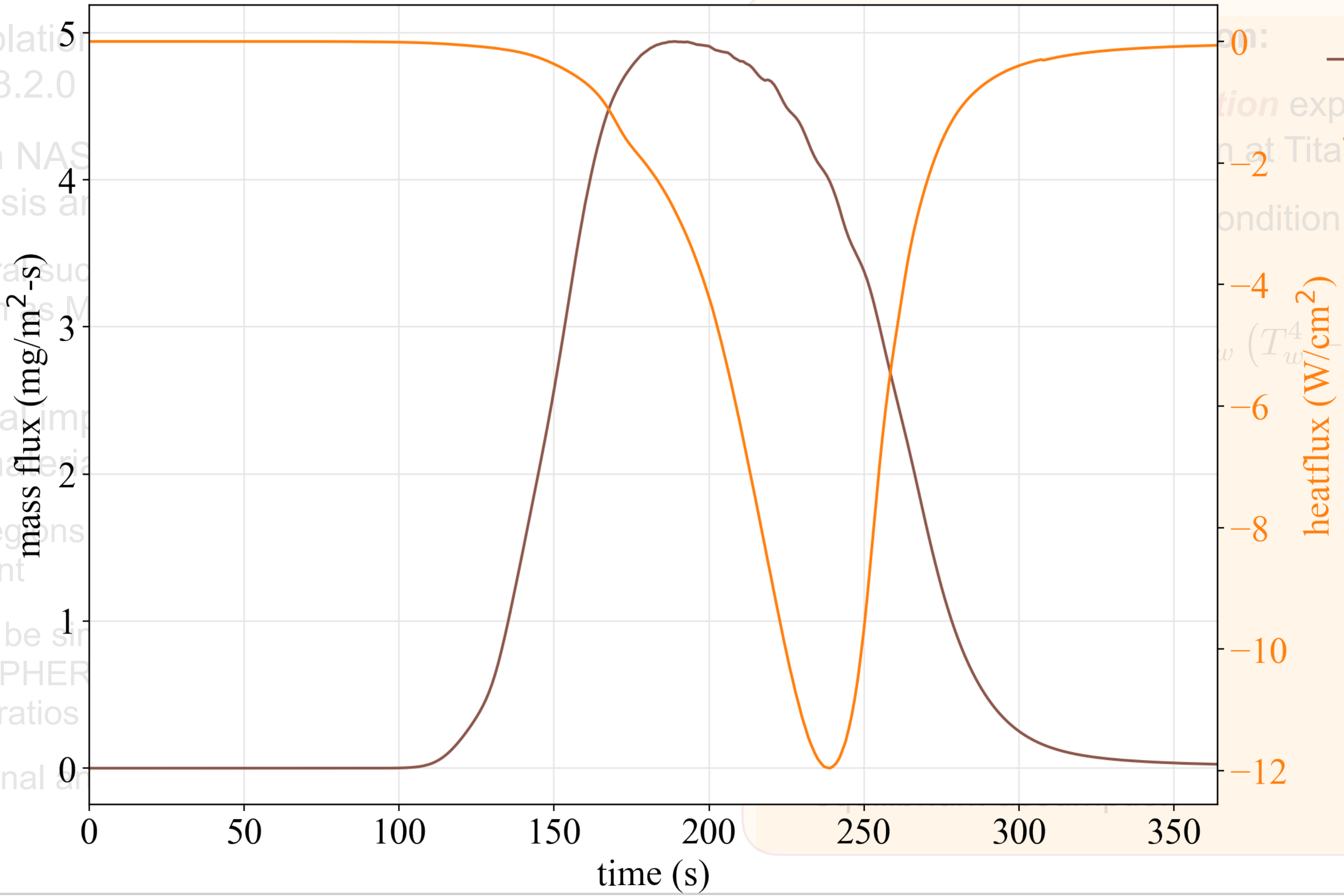

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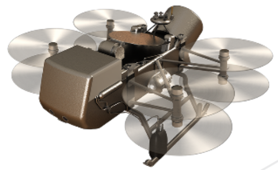
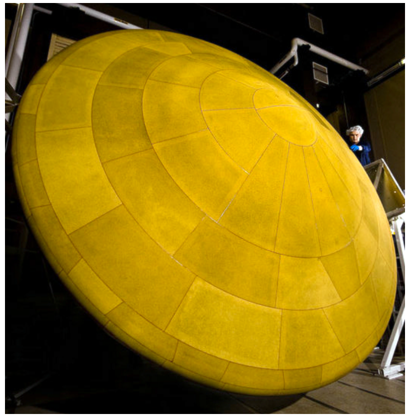
Sizing Summary



PICA Sizing		
	Thickness (in)	
	Stagnation Point	**Fore Shoulder**
Nominal	0.82	0.70
Thermal	1.01	0.87
Aerothermal	0.90	0.78
RSS	1.03	0.88
Manufacturing Tolerance	0.02	0.02
	1.05	**0.90**

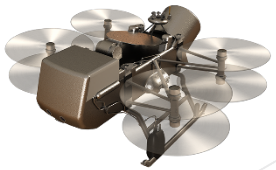
Current Design Thickness	1.25	1.19
Factor of Safety	**17.6%**	**29.7%**

- Stagnation point drives PICA sizing, despite higher heating at shoulder
  - Result of greater thermal mass of shoulder structure



Tiled PICA heatshield of MSL

Sizing Summary



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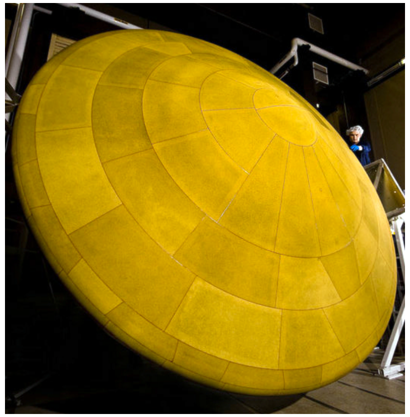

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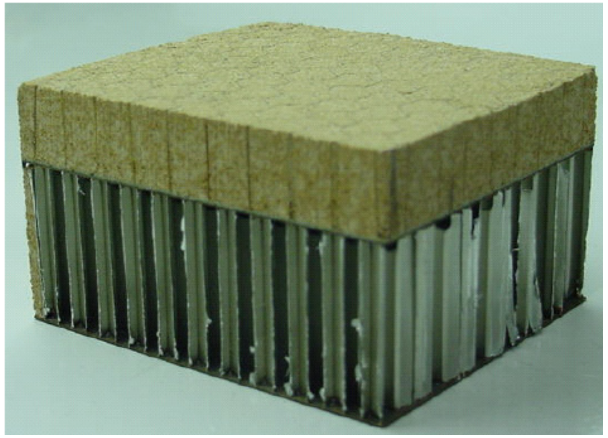

SLA-561V coupon (not representative of flight configuration)

SLA-561V Sizing	
Aftbody Shoulder	Parachute Cone
0.27	0.14
0.30	0.20
0.35	0.25
0.36	0.27
0.03	0.03
0.39	**0.30**

0.50	0.50
21.9%	**58.3%**

- Current backshell design thickness has ample unallocated margin

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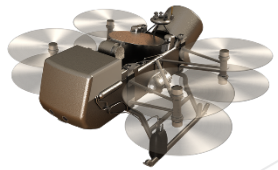
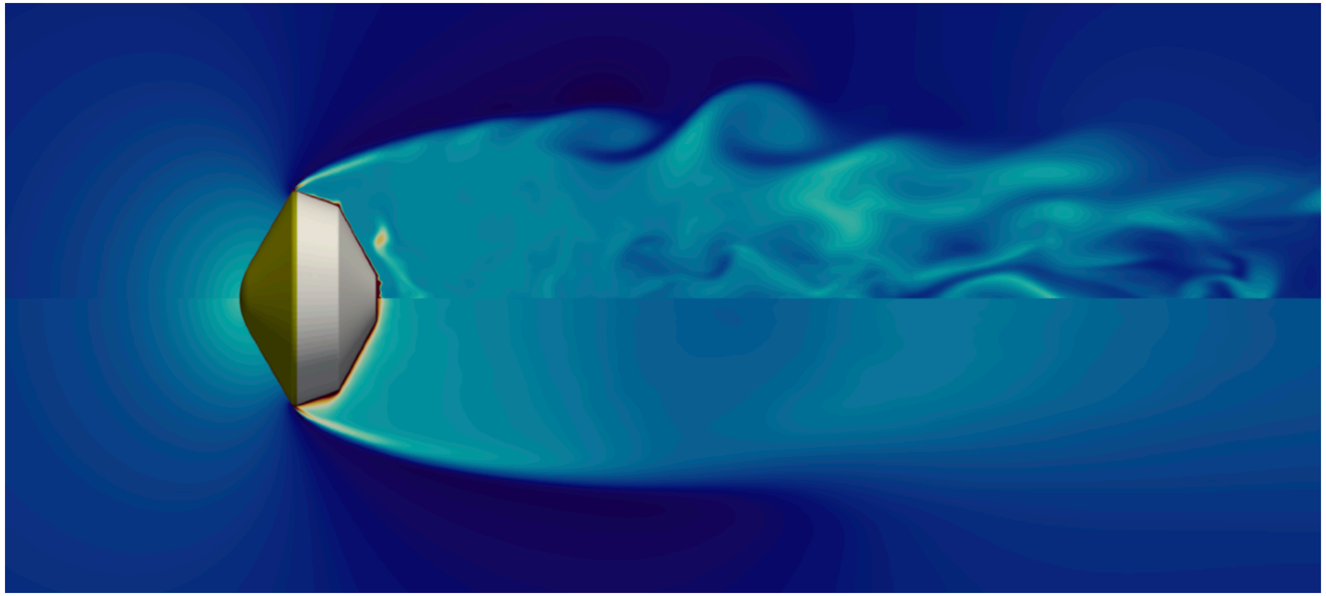
Unique Challenges for Titan EDL



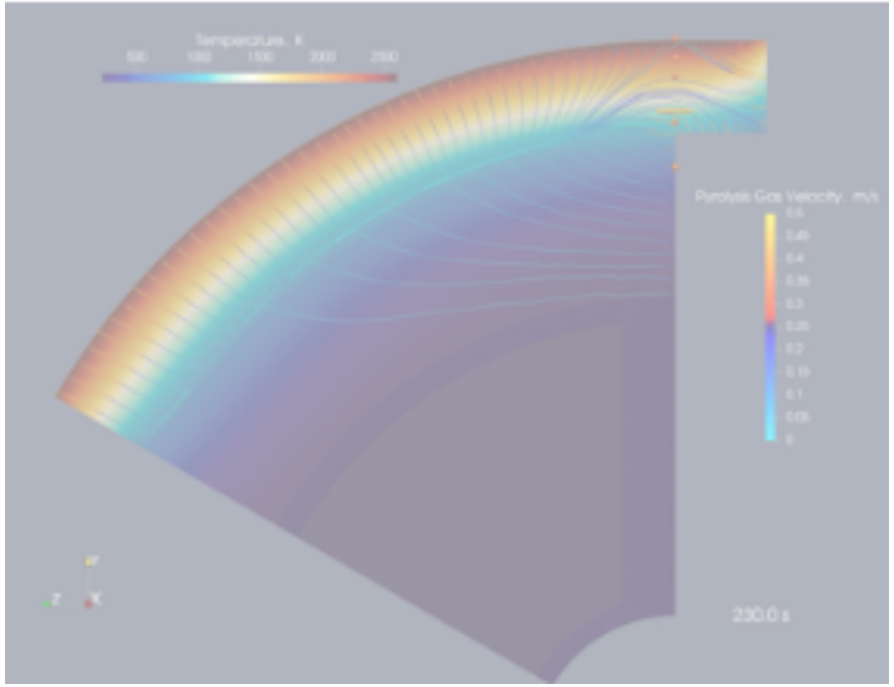


Convective Cooling During Descent

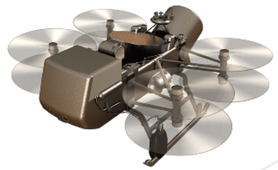
- **Problem**: *Very* long descent time under drogue, and enclosed MMRTG, results in complex thermal management problem
- Thermal analysis is very sensitive to assumed model for cooling from cryogenic atmosphere
- Empirical convection coefficients from literature have broad range (~5 - 200 W/m^2-K)

Main Seal Environment:

- **Problem**: High radiative heating at shoulder exceeds main seal material performance limits
- Novel TPS designs being explored to mitigate

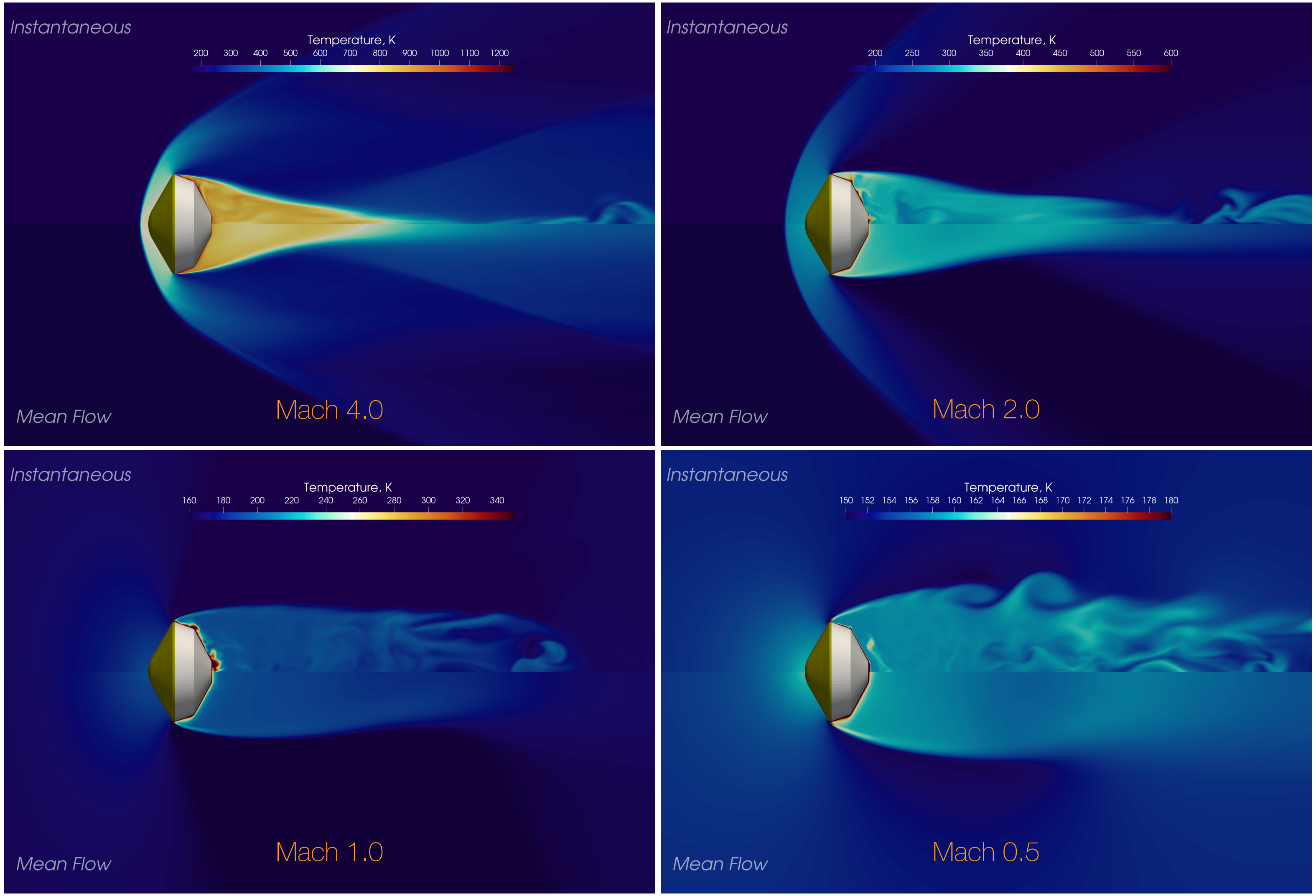


Simulations of Convective Cooling

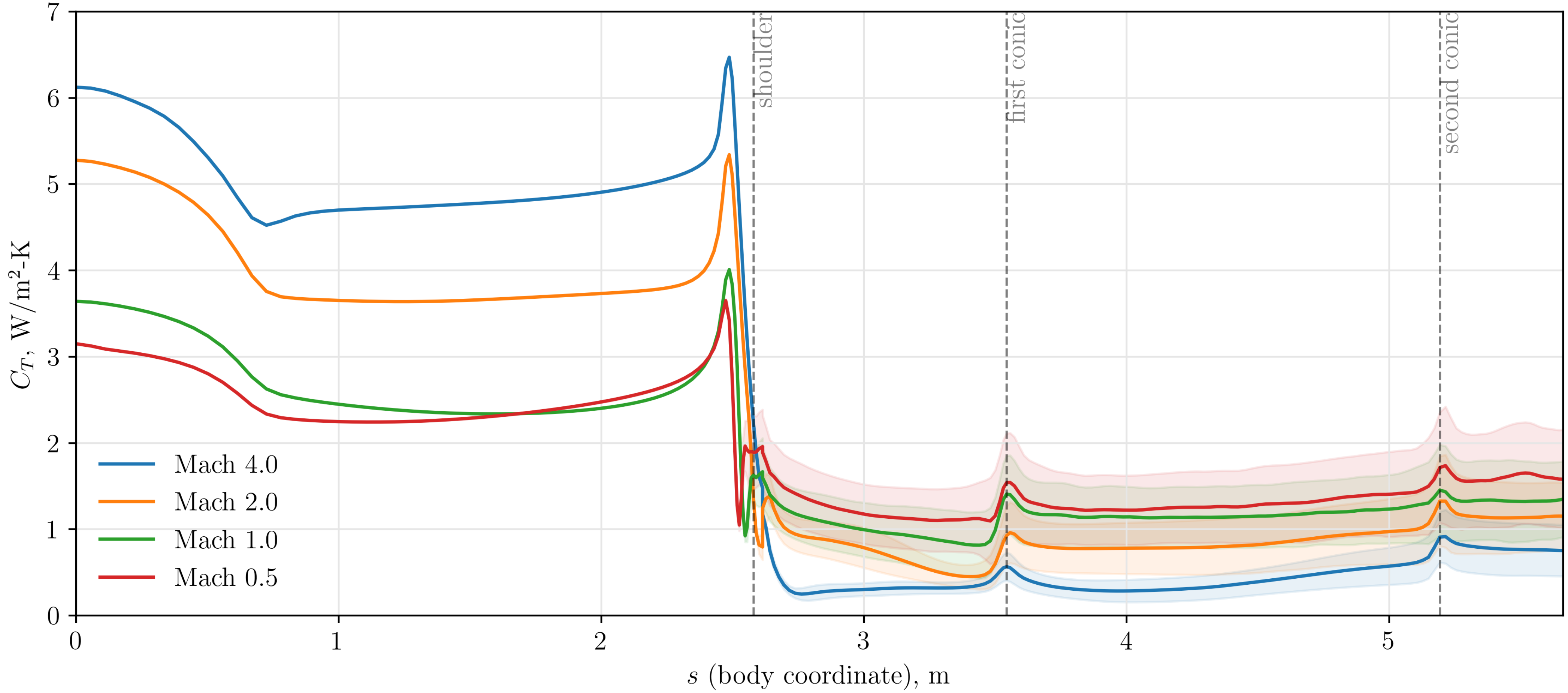


- **Constructing small database of US3D simulation to predict cooling coefficient:**
  - Freestream conditions taken from CSR trajectory
  - Wall temperature set to stagnation point prediction from CSR
  - At least 500 flow times (D/V) simulated at each trajectory point
  - Grid: ~9 million elements

time	ρ_∞	T_∞	u_∞	M_∞	T_w
s	kg/m^3	K	m/s		K
279	0.0029	165.8	1061.8	4.00	1225.6
317	0.0042	163.3	524.7	2.00	796.4
364	0.0054	161.2	260.8	1.00	660.4
534	0.0103	153.4	126.8	0.50	501.5



Convective Cooling Coefficient Profiles



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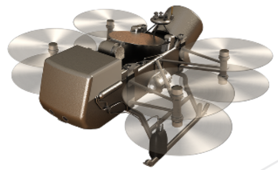
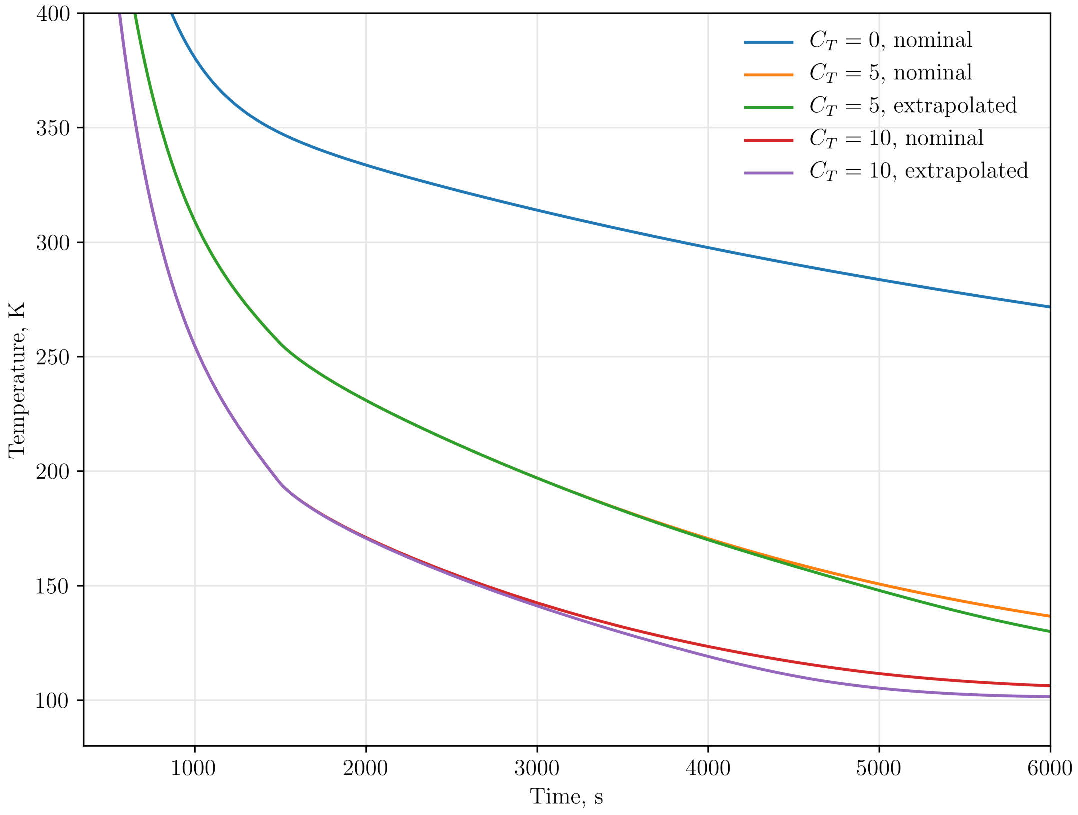
Convective Cooling Effect on Heatshield

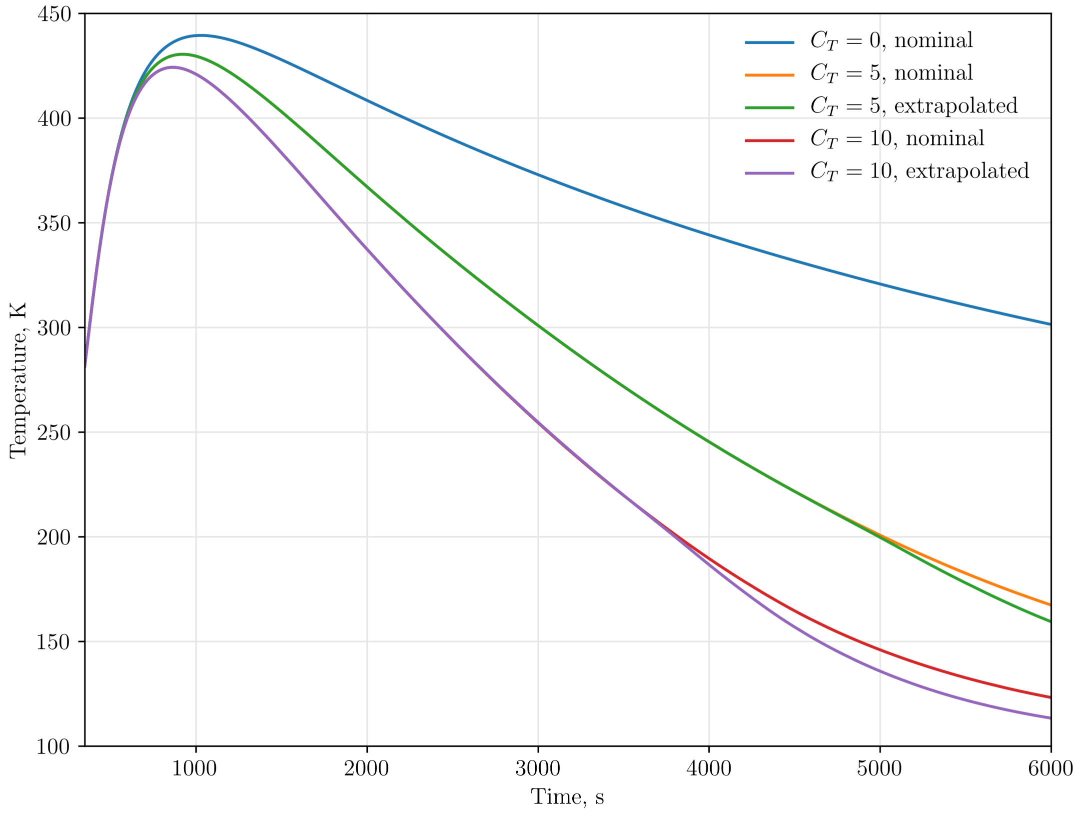


Surface Temperature



Bondline Temperature

(IML temperature within 1-2K)



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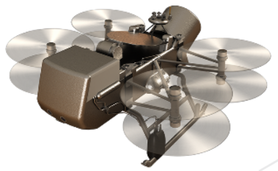

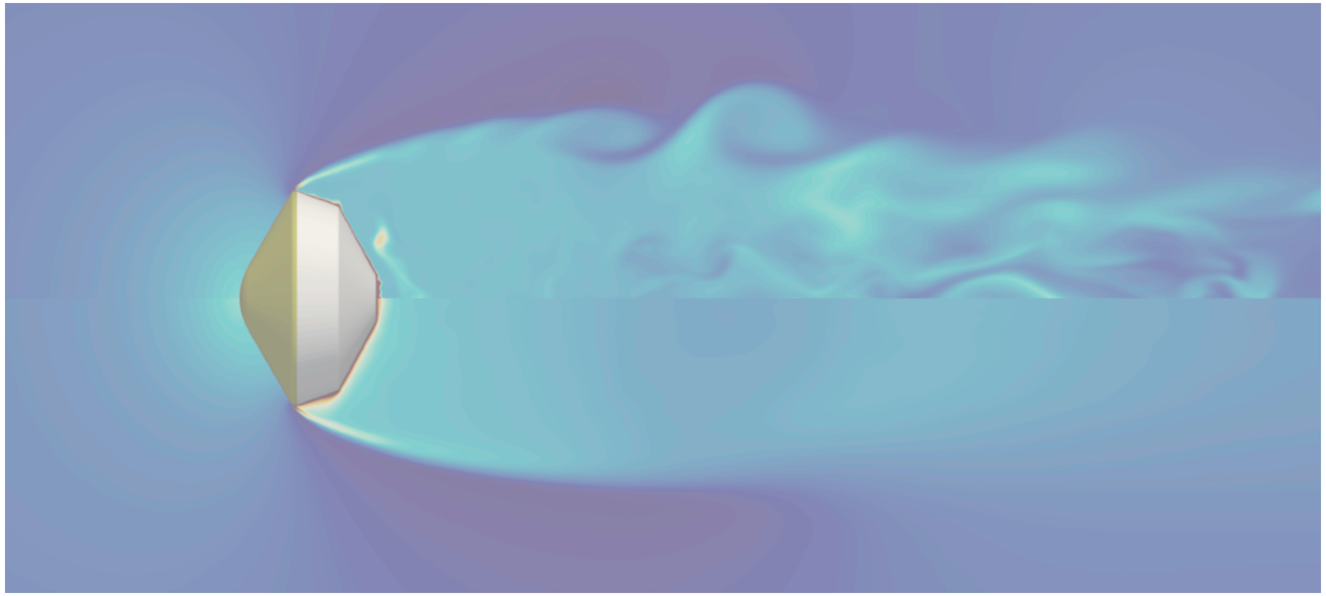

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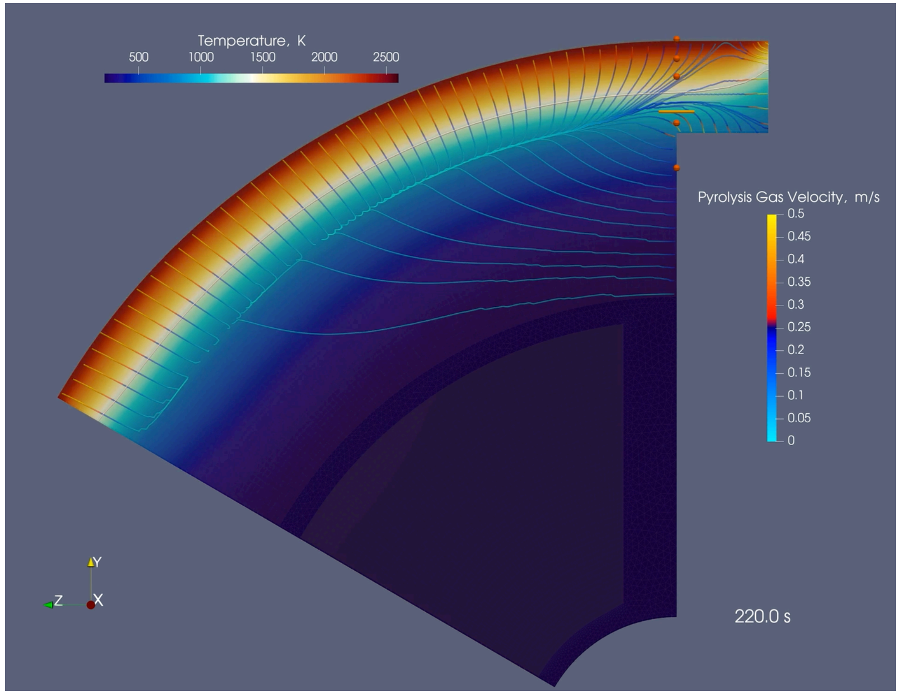
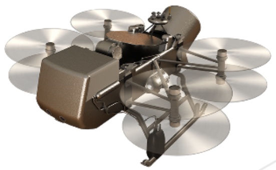
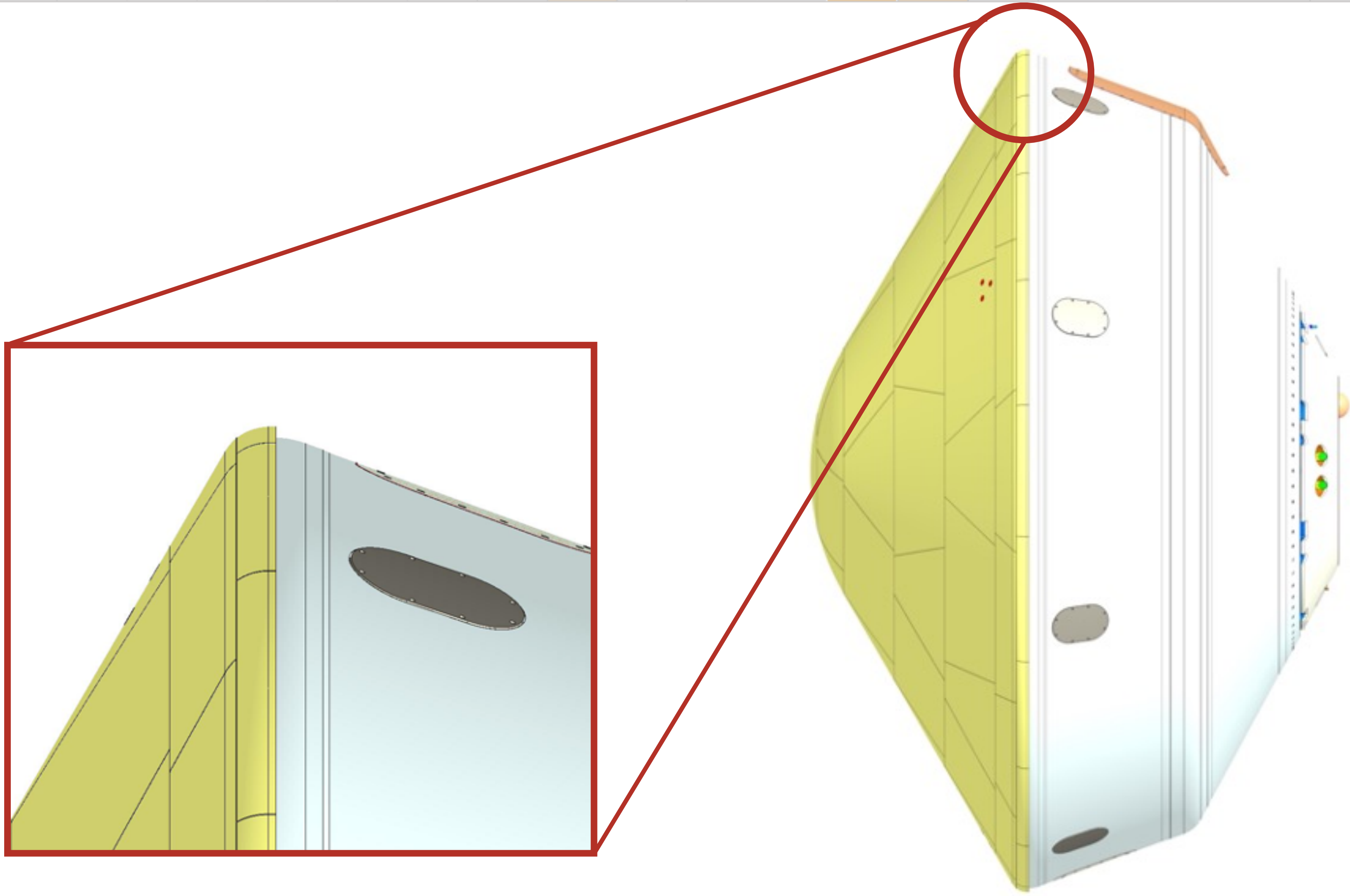


The PICA "Tooth"

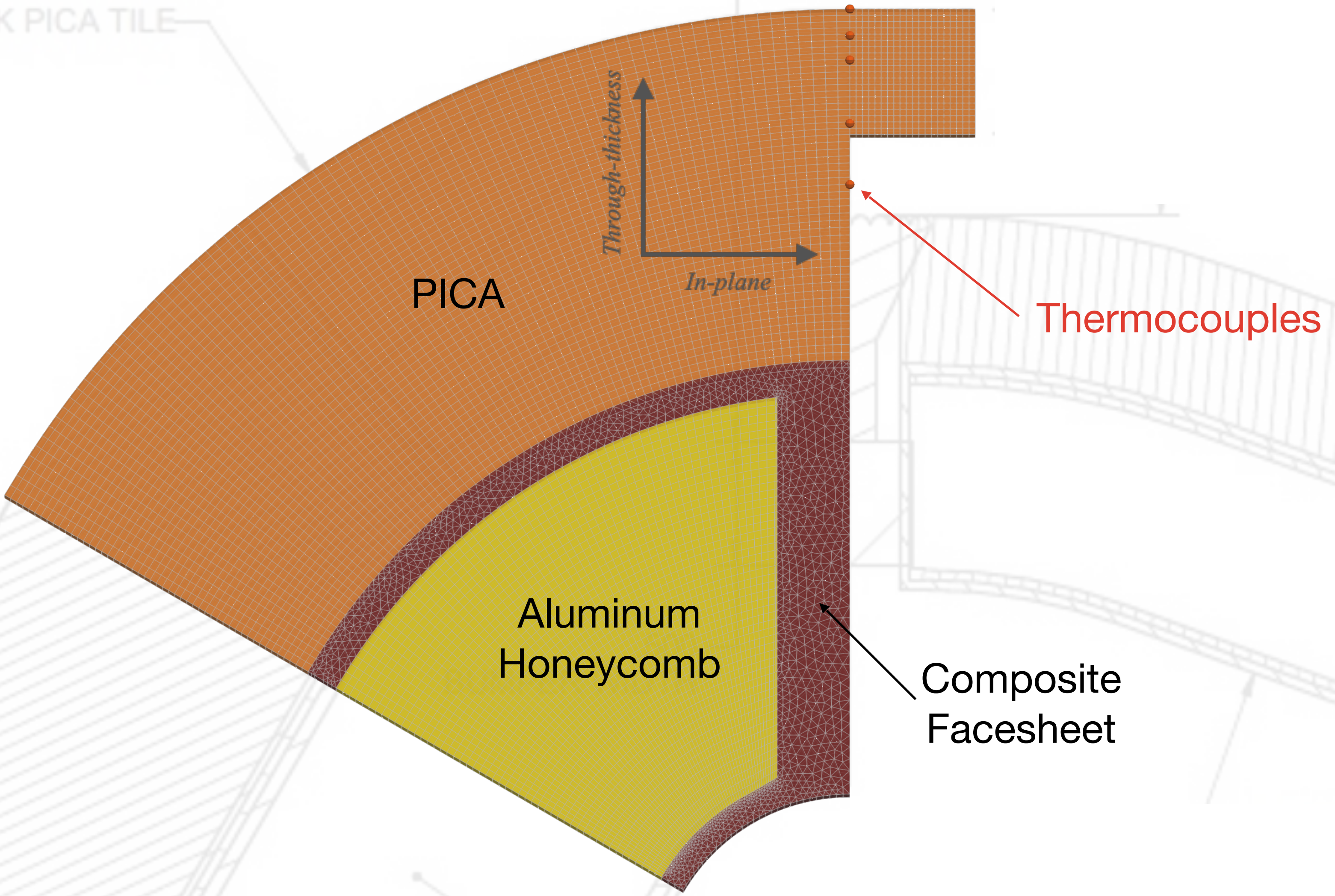


- One mitigation being explored entails extending the PICA shoulder tile over the main seal to shadow the seal from the radiative heating
- Requires detailed TPS analysis approach to analyze material response of this complex feature

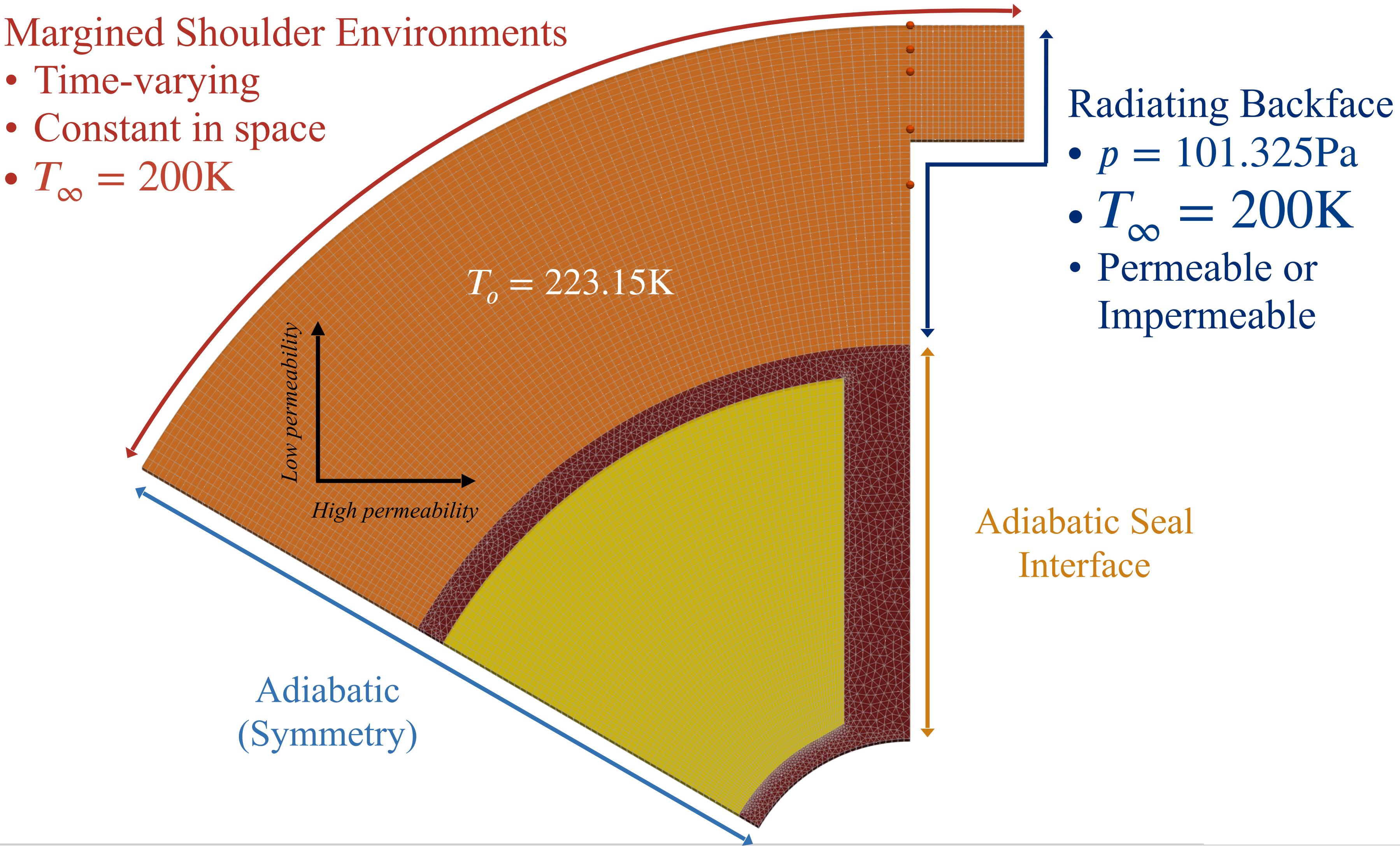


Computational Set-up: Mesh

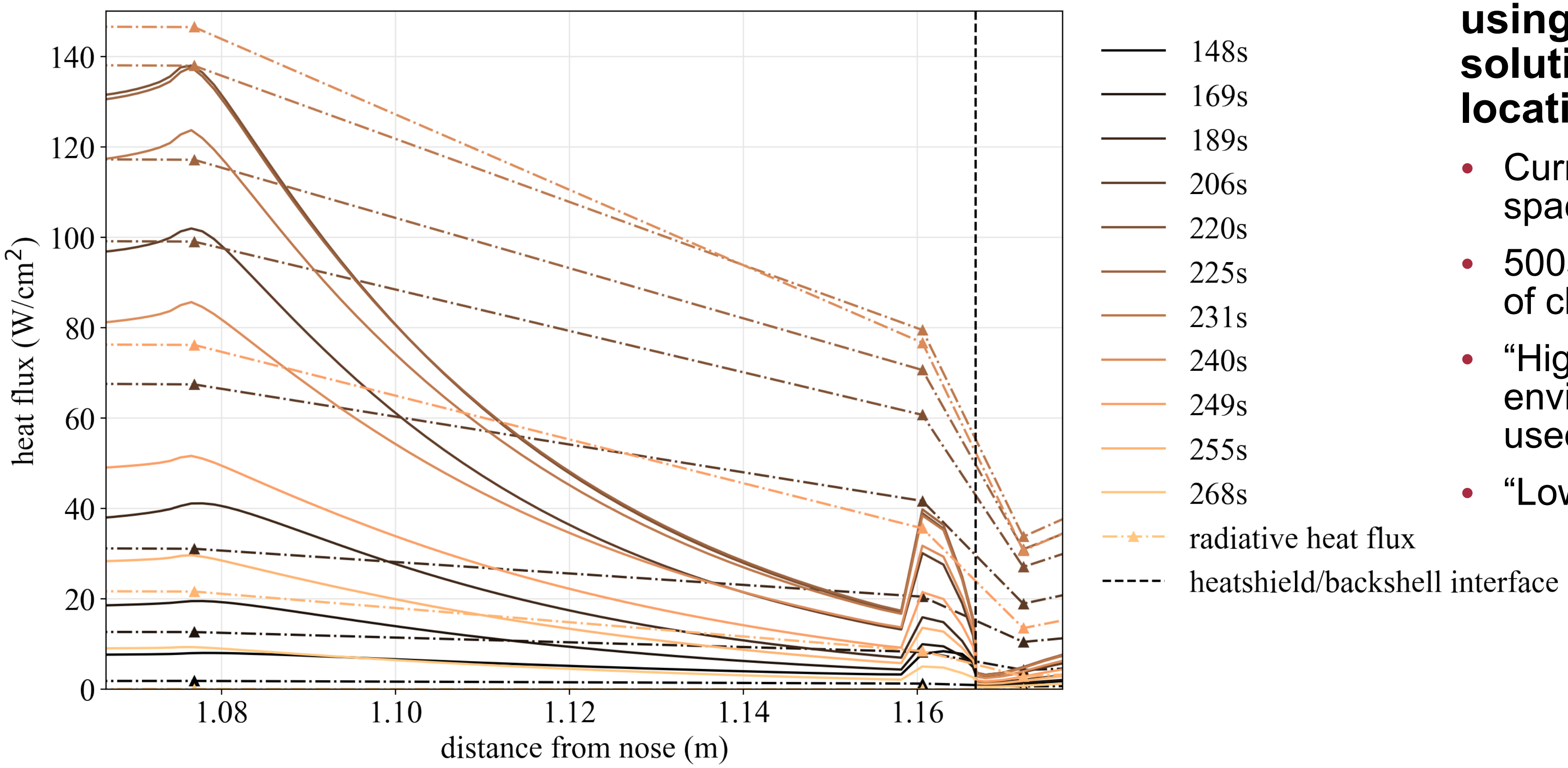
- **Preliminary multi-dimensional analysis has been performed to examine notional PICA "tooth" design**
  - Icarus used for material response simulations
  - Simplified TPS structure definition used for simulations
  - Array of thermocouples placed at apex for comparison with 1D simulations



Computational Set-up: Boundary Conditions



Environment



- **For preliminary analysis, two environments are constructed using existing aerothermal solutions at TPS sizing locations**
  - Currently, heating is uniform in space, but varying in time
  - 500s of trajectory simulated (end of charring)
  - “High” is the worst case environment, which has been used for TPS sizing
  - “Low” is closer to the tooth

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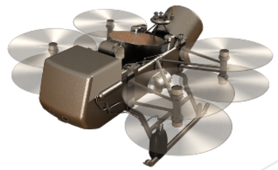

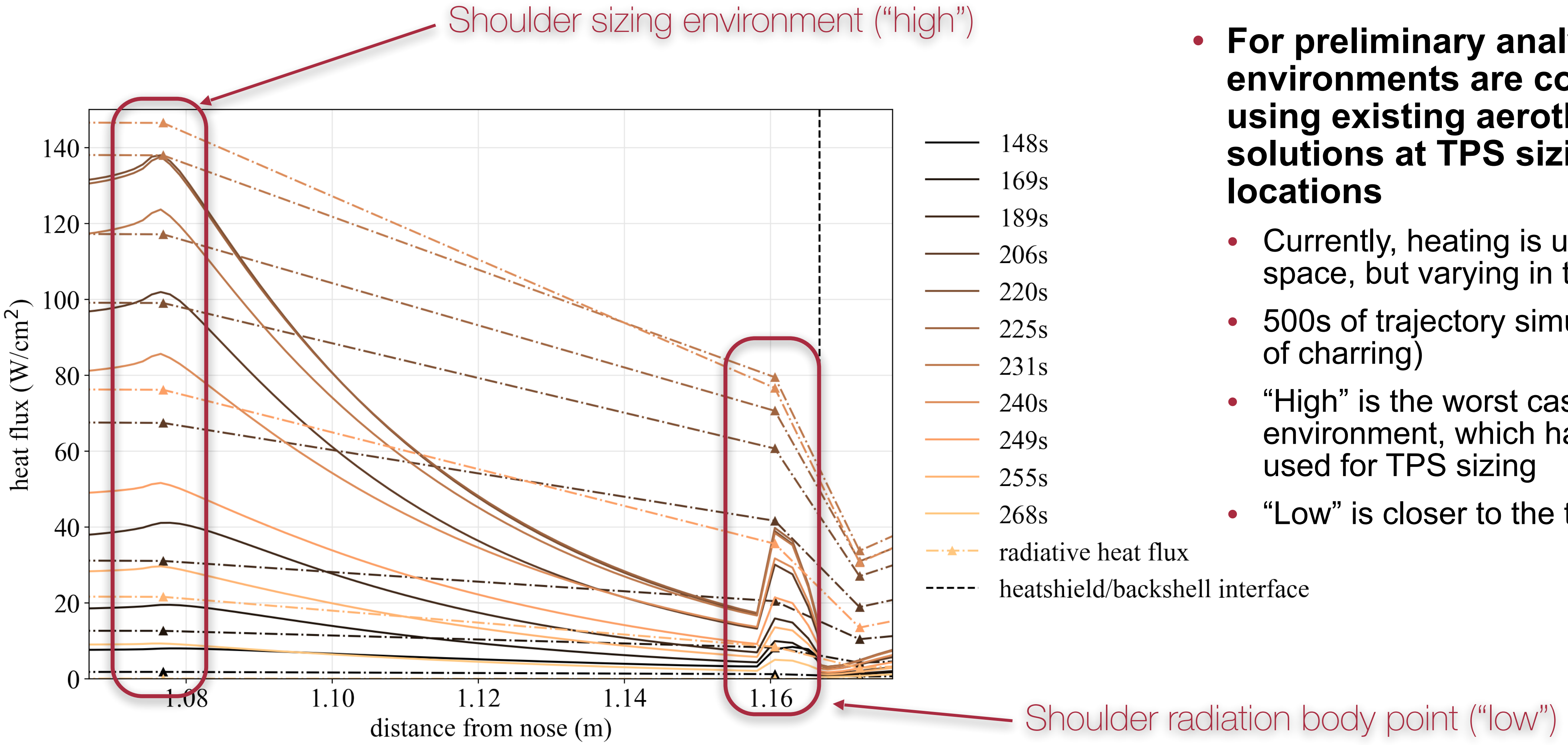

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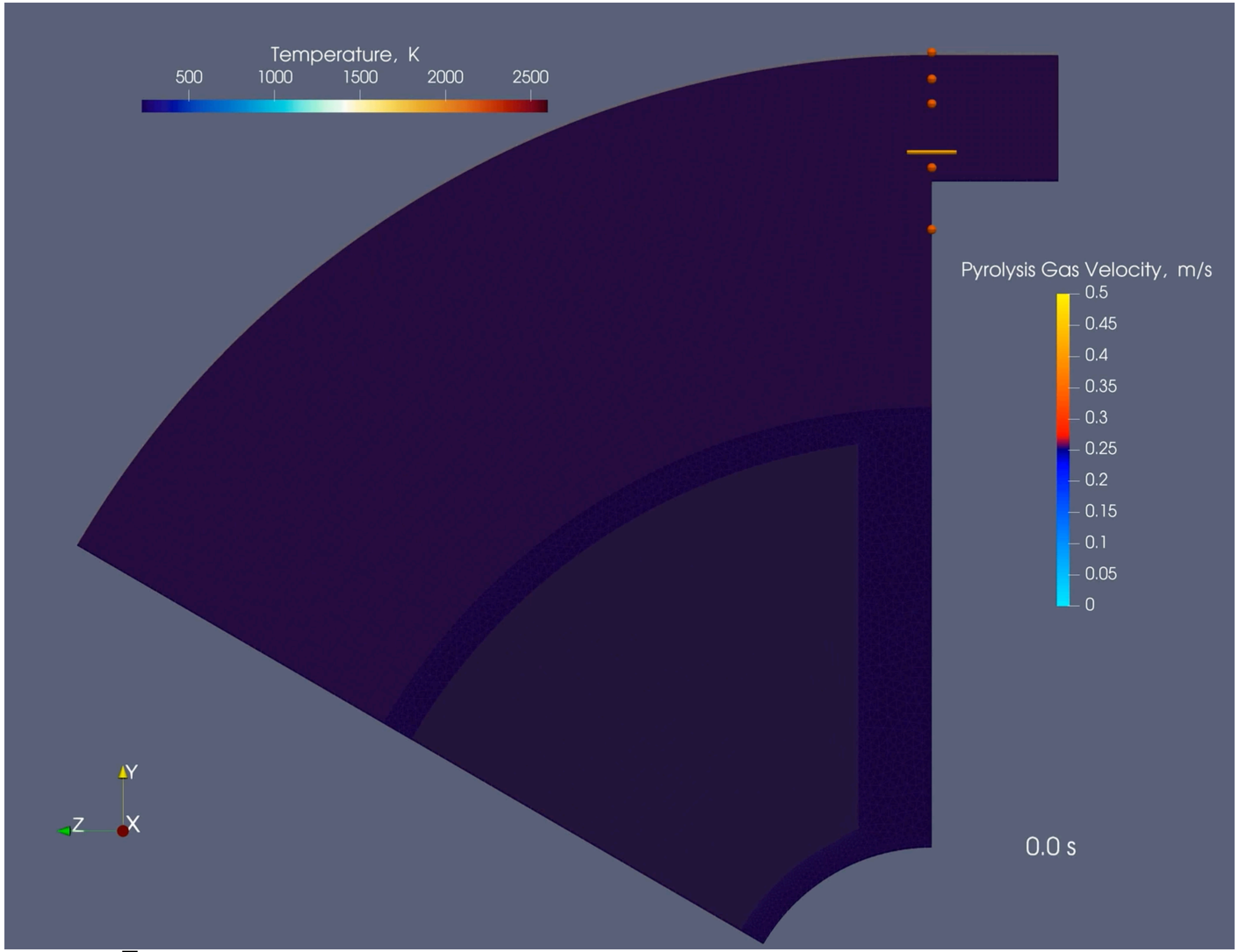
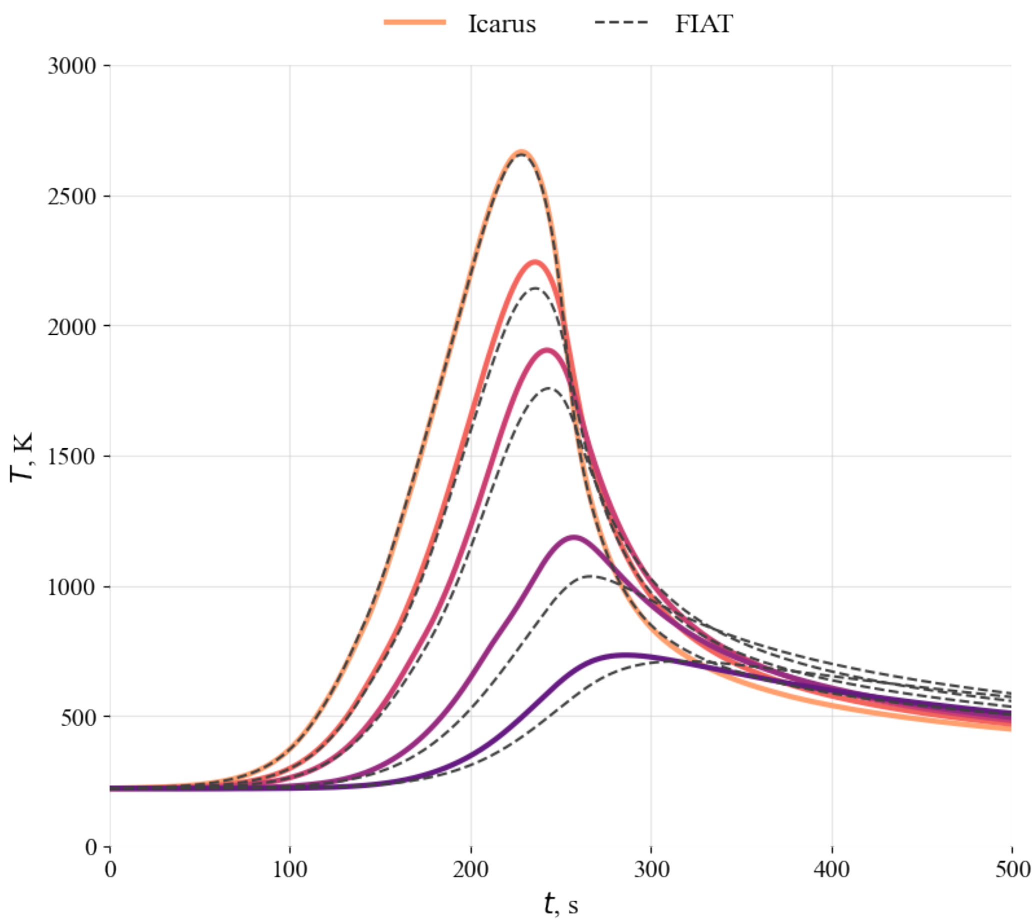
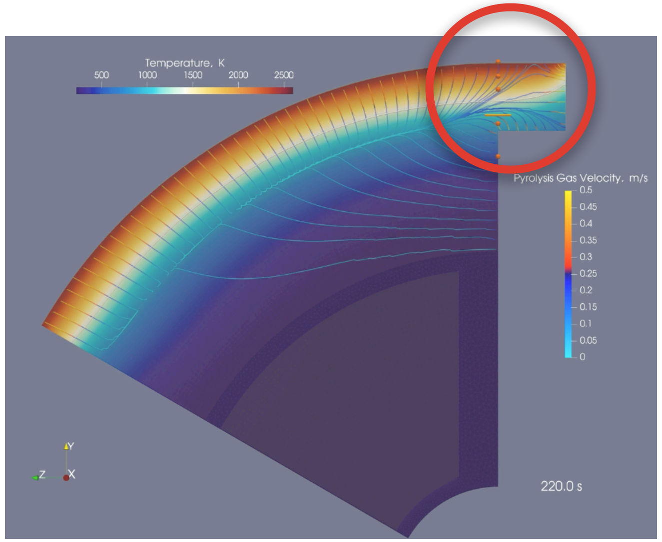
Permeable Backward Facing Step ("high" condition)

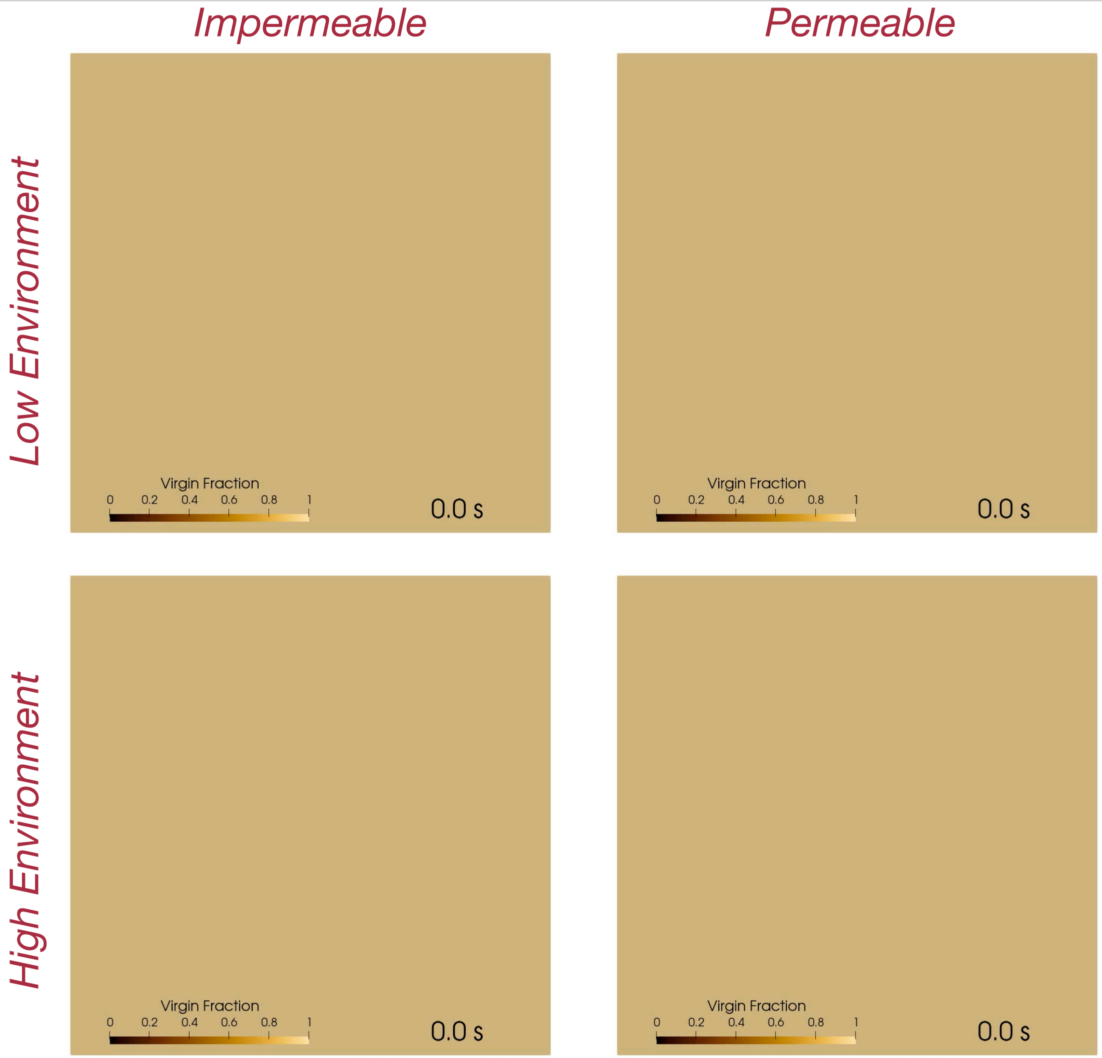




Comparison of Predicted Charring

- Results for four cases span scenarios from essentially fully charred (high environment/ permeable), to less than half-charred (low environment/permeable)
- Red curve represents 98% charred contour





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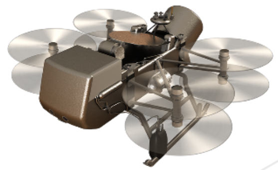
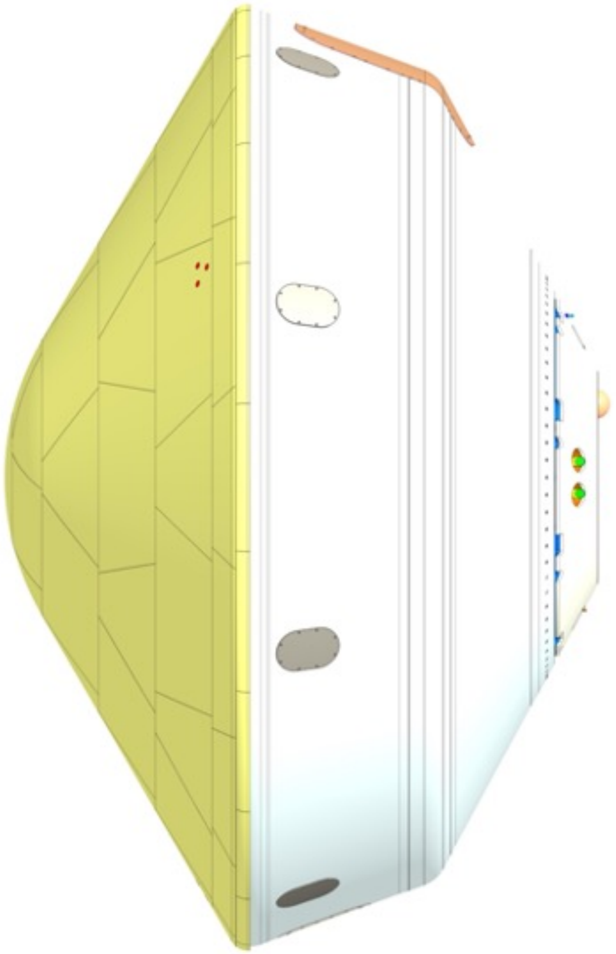


- **TPS Overview and Sizing**
  - Approach taken to size Dragonfly heatshield and backshell was presented
  - Current TPS design has ample conservatism to accommodate future design iterations
- **Dragonfly-specific TPS Design Considerations**
  - Modeling the convective cooling of the aeroshell in Titan’s environment has a strong effect on its thermal performance
  - Titan-specific models for convective cooling are currently being developed
  - A multi-dimensional simulation methodology for analyzing candidate Dragonfly main seal designs has been developed and demonstrated



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